Consumers or users? The impact of user learning about smart hybrid heat pumps on policy trajectories for heat decarbonisation

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Consumers or users? The impact of user learning about smart hybrid heat pumps on policy trajectories for heat decarbonisation

Bryony Parrish*[1], Sabine Hielscher[1,2], Timothy J. Foxon[1]

*Corresponding author, Science Policy Research Unit (SPRU), University of Sussex
Jubilee Building, Falmer, East Sussex, BN1 9SL email b.parrish@sussex.ac.uk

[1] Science Policy Research Unit (SPRU), Business School, University of Sussex, United Kingdom

[2] Technische Universität Berlin, Germany

Highlights

- Presents findings on user engagement from first UK trial of smart hybrid heat pumps
- Domestication theory offers insights for UK heat decarbonisation policy
- User learning about smart hybrid heat may challenge policy expectations
- Opportunities to influence user learning are also identified
- Energy policy could benefit from considering use as well as uptake of technologies

Abstract
Decarbonisation policies often emphasise the uptake of new end-use technologies, seeing people as consumers of technologies with predictable impacts. In the UK, smart hybrid heat pumps (SHHP) have attracted policy interest as a technology potentially offering multiple benefits for home heat decarbonisation. This paper draws on domestication theory, a perspective that frames people as *users* who actively learn about technologies, to analyse interviews and observations with installers and users involved in the first UK trial of SHHP. This perspective reveals that that users' learning about SHHPs may erode part of the energy savings they offer and have implications for future technology uptake, including the trajectories of heat decarbonisation currently envisaged by policy makers. However, it also reveals opportunities for policy making to influence user learning, including paying closer attention to material elements such as radiator controls and space to air laundry alongside improved information provision. This could be supported by engaging with users as their learning emerges over time. Overall, the paper highlights the policy relevance of technology use as well as uptake and adds to calls for energy policy to think beyond information provision and economic incentives to engage with households, implying a less deterministic approach to policy making.

Keywords: heat decarbonisation; smart hybrid heat pumps; domestication; users; energy policy

1. Introduction

New end-use technologies are expected to play important roles in reducing carbon emissions, making them common targets of energy policy (e.g. IEA, 2010; HM Government, 2011). Heat decarbonisation is currently an important energy policy topic in many regions (BEIS, 2018; CCC, 2019b; IEA, 2019). In the UK, smart hybrid heat pumps (SHHP) are an innovative end-use technology that has recently attracted policy attention, with the Committee on Climate Change recommending that around 10 million could be installed between 2020 and 2035 (CCC, 2018, 2019b). The UK department of Business, Energy and Industrial Strategy (2018) have also expressed interest in hybrid systems and the Environmental Audit Committee are now consulting on the potential role of hybrids and other forms of heat pumps (UK Parliament, 2020b).

Hybrid heat pumps combine electric heat pumps with a gas boiler, a combination which offers significant technical potential for decarbonising domestic heating. The possibility of switching between electricity and gas for heating could overcome technical challenges associated with the large-scale deployment of stand-alone heat pumps, such as the need to greatly increase electricity generation and network capacity (CCC, 2018). Hybrid heat pumps can operate with existing radiators instead of requiring larger heat emitters to be installed; are designed to provide heating profiles similar to those UK users are familiar with; and could also offer demand response services to the electricity system ('FREEDOM Project Final Report', 2018).

Policies aiming to reduce emissions through new end-use technologies often involves identifying promising technologies and then promoting their uptake, drawing on insights from engineering and economics (Shove, 2010; Evans, McMeekin and Southerton, 2012; Spurling *et al.*, 2013; Labanca and Bertoldi, 2018). However, this narrow view of how emissions reductions can be achieved may limit policy effectiveness (Jensen *et al.*, 2019; Royston and Foulds, 2019). One limitation of focussing only on the technical potential and uptake of new end-use technologies is that it overlooks the role of *use* in determining technology impacts (Sørensen, 2006) including emissions reduction (Sørensen, 2013).

Domestication is one alternative theoretical perspective that considers both the uptake and use of new technologies. It emphasises that users play active roles in constructing how technologies are used and the symbolic meanings attached to them, and that this contributes to trajectories of technological development on a societal scale (Sørensen, 2006). By drawing attention to people's roles as users as well as consumers of technology, domestication theory can also suggest opportunities to improve policy making (Sørensen, 2013).

This paper applies concepts from domestication theory to analyse findings from a regulator funded and industry led trial of SHHP ('FREEDOM Project Final Report', 2018) which informed the Committee on Climate Change's recommendation to roll out hybrid heat pumps at scale as part of a trajectory of domestic heat decarbonisation (CCC, 2018, 2019b). Because domestication theory conceptualises users' construction of use and meaning as resulting from different types of learning about new technologies, this paper addresses the questions: What were the outcomes and processes of user learning about smart hybrid heat pumps in the context of the FREEDOM project trial? And, what are the implications for UK heat decarbonisation policy?

The analysis identifies ways in which users' learning challenges policy expectations about future trajectories of technology deployment. It also identifies ways in which policy might influence users' learning. In doing so, it adds to arguments that energy policy would benefit from looking beyond dominant ideas of predictable technology impact, and of information provision and economic incentives as ways to engage with households as technology consumers (Sørensen, 2013; Labanca and Bertoldi, 2018; Jensen *et al.*, 2019; Royston and Foulds, 2019).

The remainder of the paper is structured as follows: Section 2 outlines the FREEDOM project trial and recent developments in UK heat decarbonisation policy, before introducing domestication theory as a conceptual framework to understand user engagement with new technologies. Section 3 describes the methodology. Sections 4 – 6 present findings and discuss the policy relevance of *what* users learned about SHHP; the policy recommendations suggested by *how* users learned about SHHP; and broader policy implications of considering user learning. Finally, Section 7 summarises conclusions and policy implications.

2. Background

2.1 UK heat decarbonisation policy and the FREEDOM project

Decarbonising domestic heating is an important next step for reducing UK carbon emissions. Around 85% of UK households use natural gas for heating (BEIS, 2018). For the UK to meet its commitment to net zero emissions, home heating must switch almost fully to low carbon sources by 2050, but progress to date has been too slow (CCC, 2019a). Alongside insulation retrofit, heat pumps have been seen as a key technology to decarbonise home heating, with lesser roles for bioenergy, combined heat and power and district heating in particular circumstances (CCC, 2010; HM Government, 2011). Policy makers began to consider the potential of hydrogen gas grids and hybrid heat pumps more recently (DECC, 2013; BEIS, 2018). Switching to full electric heating provided by heat pumps or developing hydrogen gas for heating would each pose significant challenges. The UK government and parliamentary committees are consulting on pathways to decarbonise heating (BEIS, 2018; UK Parliament, 2020a), and on the potential of electric, gas, and hybrid heat pumps as part of this (UK Parliament, 2020b).

Hybrid heat pumps combine an electrically driven heat pump with a gas boiler, allowing strategic switching between gas and electricity use for heating. The Committee on Climate Change (2018, 2019) have recommended rolling out hybrid heat pumps at scale to on-gas homes, suggesting around 10 million could be installed between 2020 and 2035. This recommendation was informed by analysis of the FREEDOM Project trial: the first trial of SHHPs in the UK, as well as the largest globally (Carter, Lancaster and Chanda, 2017; Sun *et al.*, 2019). It trialled hybrid systems comprising air source heat pumps and gas boilers which were installed, free of charge, in 75 homes in South Wales ('FREEDOM Project Final Report', 2018). Analysis of the trial data, including modelling at UK system level (Imperial College, 2018), suggests that hybrid heat pumps could reduce system costs compared to full electrification: reducing the need for new electricity generation and network capacity, and enabling demand response via fuel switching between electricity and gas and the storage inherent in the gas network. At the household level, they also allow the use of relatively small heat pumps, and can operate effectively without upgrading building thermal insulation or systems of heat distribution, reducing capital costs and disruption in the near term. Smart controls developed for the trial automatically minimised running costs. They allowed users to set their desired heating profile using a smart phone app and wall mounted thermostat, while automating the timing of heat pump and gas boiler operation in response to users' settings, the time taken for individual homes to heat and cool, and different forms of demand response tested over the course of the trial, including varying gas and electricity pricing and direct control of heat pumps ('FREEDOM Project Final Report', 2018).

Expectations about the benefits of SHHP rest in part on expectations about their users. Smart controls are key to achieving the technical benefits on offer because they mediate fuel switching between electricity and gas; achieving these technical benefits therefore implies that uptake and use of the smart controls proceeds as expected. Furthermore, the CCC (2018) identify hybrid heat pumps as a "low regret" option that can reduce carbon emissions in the near term while maintaining the possibility of either full electrification, or development of a hydrogen gas grid in the future. This is based in part on the expectation that hybrid heat pumps would increase public familiarity with heat pumps in a way that supports any later transition to full heat pumps if this is desirable (CCC, 2018).

The analysis in this paper refers to two documents produced by the Committee on Climate Change (CCC) as these were also informed by analysis of the FREEDOM project trial (CCC, 2018, 2019b). The CCC have an advisory role (CCC, 2008), with Business, Energy and Industrial strategy (BEIS) and formerly the Department of Energy and Climate Change (DECC) having primary responsibility for policy implementation. However, the CCC's analysis has previously informed heat decarbonisation strategy (DECC, 2012), and is informing further strategy development (BEIS, 2018).

The consumer appeal and acceptability of the trial technology were assessed during the trial via a focus group and series of participant surveys ('FREEDOM Project Final Report', 2018). Other work has focussed on the design of smart control user interfaces (Stumpf *et al.*, 2018) and on identifying households' current preferred heating patterns and their implications for policy (Hanmer *et al.*, 2019). This paper contributes to knowledge of UK households' engagement with SHHP by taking a broader look at the ways in which they are used as part of everyday lives. To do this it draws on domestication theory, which the following sub-section introduces in greater detail.

2.2 Domestication theory as a framework for understanding user engagement with new technologies

Energy policy often focuses on deploying new end-use technologies to decarbonise energy services such as home heating. Insights from theoretical perspectives such as economics, behavioural economics and social psychology can inform interventions to promote technology uptake, and are used to support policy making more often than other social science perspectives (Shove, 2010; Evans, McMeekin and Southerton, 2012; Spurling *et al.*, 2013; Labanca and Bertoldi, 2018; Jensen *et al.*, 2019; Royston and Foulds, 2019). Studies drawing on such perspectives include Hafner *et al.* (2019) who, drawing on concepts from environmental psychology, found that UK homeowners' stated intention to purchase and install heat pumps was increased by framing heat pump choice as a social norm. Michelsen and Madlener (2013) combined concepts from social psychology and diffusion of innovations to survey German homeowners who had installed a renewable heating system with funding from a government grant. They found that most households installed solar thermal heating to supplement a boiler, because they saw this technology as more compatible with their existing routines. Heat pumps were installed more rarely, by households motivated by multiple factors including energy prices and environmental protection as well as comfort and convenience. Policy implications include the suggestion that policies to promote uptake of renewable heating systems should address these multiple motivation – for example, combining financial incentives such as grants with information campaigns or technology demonstrations to communicate non-economic aspects of renewable heating systems (Michelsen and Madlener, 2013).

However, technologies' impact is determined by their *use*, as well as uptake (Sørensen, 2006, 2013). Perspectives that focus only on technology uptake overlook the importance of technology use. Domestication theory offers one alternative theoretical perspective that considers both uptake and use of new technologies. It highlights how users can shape new technologies as they integrate them into their daily routines, a process conceptualised as resulting from three types of learning by users (Oudshoorn and Pinch, 2003; Sørensen, 2006):

- Cognitive learning involves constructing *understanding* of the technology
- Practical learning involves developing patterns and ways to *use* the technology
- Symbolic learning involves constructing the *meaning* of the technology

Thus, users may change the meaning and/or use of the technology, decide not to use the technology, or even take action to oppose it (Oudshoorn and Pinch, 2003; Sørensen, 2006). As the meanings and use of technologies evolve across society, they can give rise to social norms and large-scale physical infrastructures, shaping opportunities for future technology development (Sørensen, 2006). While drawing attention to the importance of these processes, domestication theory can also suggest fresh opportunities for policy making (Sørensen, 2013).

Domestication theory has previously been applied to examine user engagement with new energy and smart home technologies (Ryghaug and Toftaker, 2014; Nyborg, 2015; Hargreaves, Wilson and Hauxwell-Baldwin, 2017; Winther and Bell, 2018), including heat pumps (Juntunen, 2014; Judson *et al.*, 2015) and direct control of appliances to provide demand response (Aune, 2002). A range of policy recommendations have been derived from this work: from designing home energy technologies that help users to incorporate new renewable technologies in their homes over time (Juntunen, 2014), to supporting peer-to-peer learning and hands on demonstrations to help users incorporate new technologies into their daily lives (Ryghaug and Toftaker, 2014; Judson *et al.*, 2015).

Other perspectives can also consider both the uptake and use of new technologies. Social practice theories conceptualise the performance of everyday life activities as drawing upon socially recognised patterns of normality, which combine elements of meanings, materials and competences. The result is often that practices are reproduced and remain stable, but change can occur for example if elements are combined in new ways. The introduction of new technologies can be conceptualised as a change in one element of social practices, which may contribute to practice change (Shove, Pantzar and Watson, 2012). Social practice theories have some similarities to domestication theory, but domestication theory focuses specifically on the uptake and use of new technologies within particular households (Ryghaug and Toftaker, 2014; Nyborg, 2015), while social practice theories do not focus on technology specifically, and have emphasised how practices are constructed at a societal level (Ingram, Shove and Watson, 2007). Work on sustainability transitions considers how technologies and society co-evolve as technologies diffuse from 'niches' to become embedded in 'regimes'. This can include changes in institutions, supply chains and infrastructure as well as social norms and user practices (Markard, Raven and Truffer, 2012). Users can play various roles in transitions, and indeed domestication theory has informed insights into some of these, but again the focus is on transition processes at societal scales (Schot et al. 2016). As well as offering analytical frameworks, alternative approaches can suggest different ways of engaging users with new technologies. Experimentation, in the form of involving users in co-creation, could improve the design of new technologies, including by consideration of how users' routines influence their sustainability impact (Liedtke *et al.*, 2015). Experimentation has also been applied to invite households to explore ways to make their routines less resource-intensive *without* changing technologies (Vadovics and Goggins, 2019). However, this approach was outside the scope of the present study, which was based on an existing trial of adoption of a new technology, and so we judged that domestication theory was the most appropriate framework for analysis of user responses.

This paper draws on insights on user learning during the use of a new technology, smart hybrid heat pumps, to identify policy implications for the UK. Overall, the analytical framework offered by domestication theory is well suited to address the research questions of this paper. By taking UK heat decarbonisation policy as the starting point for analysis, the paper also highlights the policy relevance of considering technology use, as well as uptake (Sørensen, 2013; Judson *et al.*, 2015; Nyborg, 2015), and adds to calls for energy policy to look beyond information provision and economic incentives as ways to engage with households (Sørensen, 2013; Labanca and Bertoldi, 2018; Jensen *et al.*, 2019; Royston and Foulds, 2019). The approach to link the analysis with policy is described in Section 3.

3. Methodology

This paper reports findings from interviews and observations with users and installers involved in the FREEDOM Project trial. Participants in the FREEDOM Project included 35 private and 40 social housing households ('FREEDOM Project Final Report', 2018). This study involved 14 private households participating in the trial. Convenience sampling was necessary because access to these households was mediated by different parties involved in organizing the trial. Table 1 summarises the composition of the households interviewed, and indicates that many interviewees had occupations relating in some way to energy or technology.

The timeline for data collection is indicated in Figure 1. Interviews and observations were conducted with participant households near the beginning and end of the trial. *Initial user interviews* related to existing routines involving heating as well as the ways in which users became involved in the trial and their experiences of installation. In six cases, it was also possible to observe the final stage of the installation process where the trial equipment and controls were explained to and set up with the users (*installation observations*). *Follow-up user interviews* related to users' routines involving heating; understandings and meanings of SHHP and use of their controls; and what led to these arising during the trial. Both initial and follow-up user interviews took place in users' homes and included any adult members of the household who wished to take part; these included 20 interviewees overall with an average interview length of 60 minutes. Following the trial, *installer interviews* were conducted with the two lead installers responsible for setting up trial controls with the users. These included the ways in which installers engaged with users over the course of the trial and their perceptions of how users had interacted with the trial technology.

All interviews were semi-structured. Topic guides were informed by domestication theory but were designed to be open enough to allow the emergence of ideas that might not be covered by this approach. The topic guide for the initial user interview was additionally informed by previous work on user interaction with heat pumps in the UK and Europe (for example The Energy Saving Trust, 2010; Roy and Caird, 2013; Juntunen, 2014; Judson *et al.*, 2015; Gram-Hanssen *et al.*, 2016), and the findings of a systematic literature review on residential user engagement with demand response (Parrish *et al.*, 2020). Reflection during each round of interviews was used to refine the topic guides, while initial analysis of earlier rounds of interviews were used to inform the development of later topic guides.

Figure 1 also indicates the papers' analytical strategy. Both initial and follow-up user interviews were analysed inductively using NVivo. This initial inductive coding identified a number of themes relating to user learning 'outcomes' (what users learned) with relevance for current UK policy on SHHP. This generated the analytical basis of the paper. Further analysis of user interviews considered how the identified learning outcomes varied across different participant households and the 'processes' of user learning that led to them. Analysis of installer interviews, installation observations and a selection of trial recruitment materials added further insights into how users learned. Analysis of learning processes was organised around the three types of learning conceptualised by domestication theory: cognitive, practical, and symbolic (see Section 2.1). Practical learning included the use of heat in the home as well as use of SHHP controls. Cognitive learning included understandings about how SHHP work and the functions they provide. Symbolic learning included meanings about SHHP, and about the trial itself. Understandings were differentiated from meanings by considering whether interviewees explained why they held a certain view; for example, not drying laundry on radiators *because* it reduces efficiency would be categorised as an understanding, but seeing hot radiators *as a sign of* an effective heating system would be categorised as a meaning.

Interviewee(s) (all names are pseudonyms)	**Household members and selected circumstances**
Lucy	Working couple with a baby. Lucy works for a utility company.
Kim and Tom	Working couple with three children. Tom works as a heating engineer.
Mike	Working couple. Mike works as a handyman and has knowledge of heat pumps, while his wife works in healthcare.
Richard and Sophie	Working couple with a child at university. Richard teaches engineering at college while Sophie works for the local council.
Alan and Carol	Retired couple with adult children. Alan worked as a carpenter.
Anne and Cai	Retired couple with adult children. Cai worked as an electricity system engineer.
Jim and Rachel	Couple with adult children, one living at home. Jim works in the electricity sector while Rachel is often at home.
Ruth and Harry	Working couple. Ruth works for the local council while Harry is a toolmaker.
Clive	Couple with adult children, two living at home.
Hayley	Couple with three young children. Hayley is a home-maker, her husband works as a carpenter.
Nick	Single man who works in a factory producing petrol engines.
Laura	Working couple with two children. Laura is a primary school teacher.
Debbie and Phil	Retired couple with adult children (declined follow-up interview)
Paul	Working couple with children. Paul works in the electricity sector.

Table 1: Interviewees' households and their circumstances

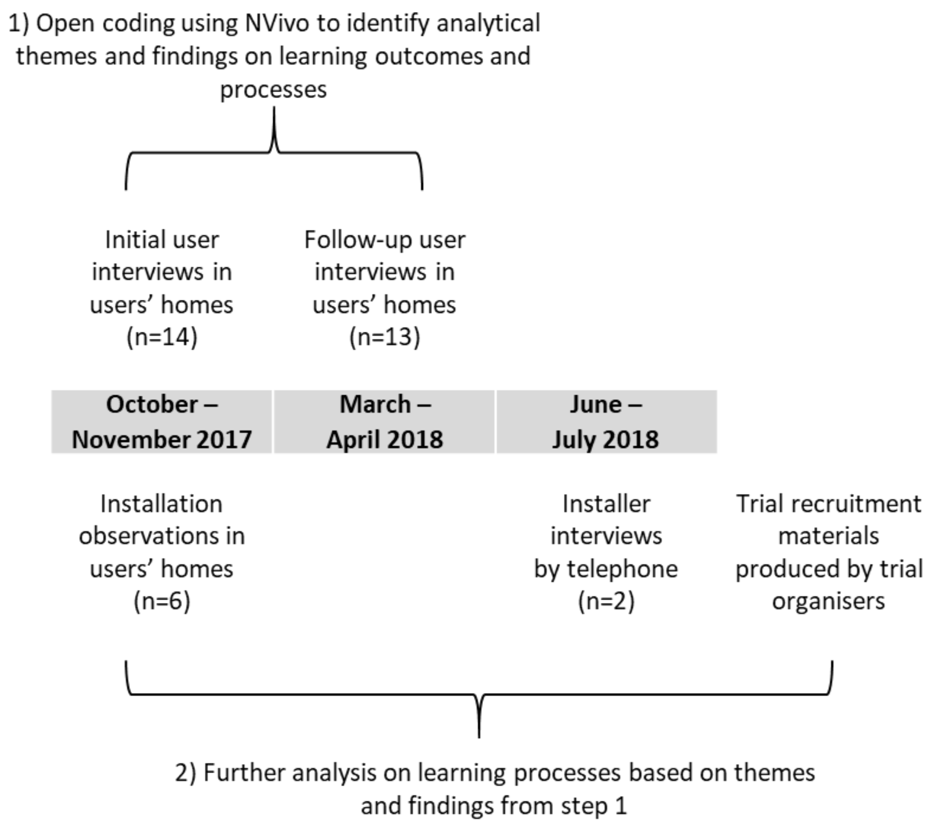

Figure 1: Timeline and strategy for data collection and analysis

4. What users learned about smart hybrid heat pumps

This section presents findings on outcomes of user learning and discusses their relevance for UK heat decarbonisation policy. Learning *outcomes* refers to the ways in which the technology was understood, used, and the meanings users associated with it that emerged from their cognitive, practical, and symbolic learning over the course of the trial. By taking UK heat decarbonisation policy as a starting point for analysis, this section aims to demonstrate the policy value of considering technology use, as well as uptake, when implementing lower carbon energy technologies within people's homes. Section 5 will then present findings on the *processes* involved in cognitive, practical, and symbolic learning before Section 6 discusses the policy implications for influencing user learning.

4.1 Learning about heat pumps as part of a hybrid system

The Committee on Climate Change identify hybrid heat pump deployment as a 'low regret' policy option, based partly on the expectation that experiencing hybrids would increase public familiarity with heat pumps in a way that supports any later transition to full heat pumps if this is desirable (CCC, 2018). However, many interviewees ended the trial believing that heat pumps are inadequate as a sole heating technology:

> "I don't understand. Technology wise, how could you not have the boiler? Because the heat pump doesn't do the work of the boiler" *(Sophie, follow-up user interview)*

This may be because users have learned about heat pumps as one component of a hybrid system, in which the gas boiler provides hot water and space heating at lower outdoor temperatures. Some users (wrongly) understand that heat pumps are unable to provide these energy services:

> "I don't think the heat pump allows us to have hot water - it, um, it solely does the heating, you know? With the boiler doing the hot water. So I don't think we could - I thought it was put to me that you couldn't simply have [a heat pump]" *(Paul, initial user interview)*

> "I was under the impression once the temperature got down to about five degrees, they virtually get to a point they can't do anything then" *(Jim, initial user interview)*

This clearly challenges the Committee on Climate Change's expectation that experiencing hybrid systems would increase public acceptance of full heat pump deployment in the future. The processes behind these learning outcomes are examined in Section 5.1. "Constructing understanding of smart hybrid heat pumps".

4.2 Learning to use smart hybrid heat pumps

It is widely recognised that introducing more efficient end-use technologies may lead to new patterns of use that off-set part of the expected energy savings (often known as direct rebound effects; see for example, Sorrell, Dimitropoulos and Sommerville, 2009). Considering how energy is used as part of everyday life can offer a fuller explanation of why new end-use technologies fail to achieve their expected impacts (Jensen *et al.*, 2018), and suggest opportunities for policy to influence these outcomes.

Interview analysis indicated two patterns of use that could reduce the efficiency benefits offered by SHHPs. Some interviewees indicated that the (technically less efficient) practice of drying laundry on radiators might be reinforced or intensified as a result of the more constant heating provided by SHHPs:

> R: “I use the radiators more, because obviously the heating is on a lot more isn't it?... jeans, you know, I don't tend to put them in the dryer because they tend to shrink a bit and that, but I can wash them and the following morning the jeans are dry.”
> Interviewer: “Just by being on the radiators?”
> R: “Just by being on the radiators.”
> J: “Because the heating is on all the time!” *(Rachel and Jim, follow-up user interview)*.

In addition, one interviewee described learning to effectively circumvent the intended operation of the smart controls in order to avoid night-time heating, which had kept himself and his wife awake:

> “The only way I could get it to sort of work to an extent was to set it on the controls to away, so we'd have to tell it we're on holidays” *(Mike, follow-up user interview)*

Because smart controls are central to achieving the expected technical benefits of hybrid heat pumps (‘FREEDOM Project Final Report’, 2018), changes in use that by-pass the operation of these controls could prevent these benefits from being realised.

The processes that influenced these learning outcomes are explored in more detail in Section 5.2, “Constructing the use of smart hybrid heat pumps”.

4.3 Learning about smart controls

The FREEDOM project trial concluded that users generally accepted smart controls (‘FREEDOM Project Final Report’, 2018), which bodes well for the prospect of achieving the technical benefits on offer from SHHPs. However, analysis of users’ learning about smart controls during the trial suggests this conclusion deserves further attention.

Interview findings suggest that users were often positive about the idea of smart control in abstract, but many appeared to be unaware of the full range of smart controls tested in the trial. When discussing smart control, interviewees commonly identified a sub-set of the controls tested: the ability of the thermostat to learn how long it takes to heat their home; fuel switching to reduce gas use; and the option to control their heating remotely. Time of use pricing (one form of demand response tested during the trial) was mentioned by a minority of interviewees: those with work experience in the electricity sector that led them to speculate about the possibility of demand response, and those who were told about it at a focus group:

> “I didn’t realise that their aim is to, um, alter the air source and the gas, and they want to... they want to run that, so that when the gas is cheaper, they'll use more gas, and when the electric is cheaper, they'll use more electric. Well, none of us in that [focus] group knew that, because we hadn't had any information about that” *(Alan, follow-up user interview)*

In addition, some interviewees who experienced changing heating profiles felt uncertain about whether this represented ‘normal’ operation or was connected to the trial in some way:

> “We've assumed that it's because of the trial they are trying different profiles of heating - if it's not that, it would alter things dramatically” *(Jim, follow-up user interview)*

Some experiences described by interviewees may indeed have been due to technical issues arising during the trial (‘FREEDOM Project Final Report’, 2018). In addition, some forms of direct control to provide response and reserve services (‘FREEDOM Project Final Report’, 2018) may have been too brief to be noticeable (Eto *et al.*, 2012; Lebosse, 2016). Nonetheless, interview findings suggest that users' apparent acceptance of smart controls might be better characterised as users not questioning automation of their heating that they were not fully aware of. Users often have a bias towards greater trust of automation with lower levels of experience (Hoff and Bashir, 2015), but over time, a lack of transparency can influence the meaning that users construct about smart automation and demand response – including the development of mistrust (Carmichael et al., 2014; Wiekens, van Grootel and Steinmeijer, 2014). Altogether this suggests that users' awareness and acceptance of smart controls requires more specific attention at an early stage, for example in any follow-up trials ('FREEDOM Project Final Report', 2018).

The processes that influenced these learning outcomes are explored in more detail in Section 5.1 and 5.3, "Constructing understanding of smart hybrid heat pumps" and "Constructing the meaning of smart hybrid heat pumps".

By focussing on learning outcomes, this section has supported the argument that technology use and user learning are relevant to energy policy. Section 5 now turns to present findings on *how* users learned about SHHPs during the trial, before Section 6 discusses opportunities for policy to influence users' learning.

5. How users learned about smart hybrid heat pumps

This section examines how users constructed understandings, uses, and meanings of SHHPs during the FREEDOM project trial. This analysis informs the policy implications identified in Section 6, which suggest how user learning might be influenced to support the envisaged role of SHHPs in UK domestic heat decarbonisation.

5.1 Constructing understanding of smart hybrid heat pumps

Cognitive learning involves users constructing *understanding* of the technology. Households' knowledge and awareness are seen as central to the uptake of new heating technologies (BEIS, 2018; CCC, 2018, 2019b), and information provision is a common policy intervention. However, interview findings suggest a number of ways in which users' cognitive learning about SHHPs may differ from a simple process of receiving expert knowledge. Paying attention to these can suggest ways to improve information provision.

Firstly, users may only be receptive to information they feel is relevant: some interviewees said they wanted installers to "just fit it up there" (Nick) or said they "don't need to understand how it works" (Harry). Perhaps because of this, installer interviews indicate that installers may limit the information they provide to users who seem less interested in technical details, instead focussing on practical issues around using the technology. Experts' desire to avoid over-burdening users with information may explain interviewees' lack of knowledge about the full range of smart controls tested as part of the trial (see Section 4.3). Installation observations indicated installers did not (routinely) provide users with information about time varying pricing or direct control of heat pumps; similarly, trial leaflets did not mention either of these forms of demand response, but did describe the features of smart controls most often mentioned by interviewees: the option for users to control their heating remotely, and the ability of the smart controls to learn how long it takes for homes to heat, detect outdoor temperatures, and switch between electricity and gas use to minimise running costs. Meanwhile, paying less attention to information with less relevance may have contributed to the misconception that heat pumps are ineffective at lower outdoor temperatures (see Section 4.1). Trial participants were given leaflets stating that heat pumps "can get heat from the air even when the outside temperature is as low as -15° C", but user interviews revealed no indication that this contributed to cognitive learning about heat pumps' technical capabilities.

Another reason for this misconception appears to be the design of hybrid heat pumps, and the way users understand installers' explanations of this. Combining heat pumps with gas boilers is central to the technical benefits on offer from hybrids, but it effectively prevents users from experiencing and evaluating heat pumps' performance as a sole heating technology. After being asked about his statement that a heat pump "doesn't put out enough heat", Harry remarked on this clearly: "if you went down and turned the gas off now, then we'd soon find out, I suppose" (follow-up user interview). Beyond this, users' understanding of heat pumps' capabilities may be influenced by the way they understand the technical language used to communicate with them:

> "When the system was explained to us, they said for it to work adequately, it had to be above… seven degrees outside… They led me to believe that the heat pump wouldn't be as efficient once they drop below that temperature." *(Debbie, initial user interview)*

Here Debbie uses the terms "adequate" and "efficient" interchangeably. Heat pumps *are* less efficient at lower outdoor temperatures (i.e. they use more electrical energy per unit of heat supplied), but this does not mean they cannot provide heat. Many other interviewees apparently conflated efficiency and effectiveness when talking about home heating. Thus, users' understanding of technical language may contribute to the misconceptions about heat pumps' technical capabilities described in Section 4.1. Section 6.1 discusses opportunities to influence users' cognitive learning, which could potentially avoid the construction of such misconceptions.

5.2 Constructing the use of smart hybrid heat pumps

Practical learning involves users developing patterns and ways to *use* the technology. Understanding these processes can help to explain why rebound effects and other unintended uses of technologies arise (Jensen *et al.*, 2018), and suggest opportunities for policy to influence these outcomes.

Interview findings indicate that the characteristics of heating provided by SHHPs can lead to practical learning in the form of changing use of heat or controls. Heating patterns during the trial differed from the two-peak morning and evening heating which most interviewees had been used to; unlike gas boilers, heat pumps operate more efficiently when they run more constantly, and heat pump electricity demand peaked at 04:00am and 14:30pm ('FREEDOM Project Final Report', 2018).

Many interviewees appreciated more constant heating during the daytime because it aligned with the ways they already used heat at home, for example to provide comfort and care; similarly, Gram-Hanssen *et al.*, (2016) identified that more continuous heating by heat pumps fits with users' desires for greater thermal comfort. More constant daytime heating may also align with the use of radiators to dry laundry, contributing to the intensification of this routine described in Section 4.2. Similarly, Judson *et al.*, (2015) found that heating from heat pumps fits well with the routine of drying laundry on radiators. No interviewees reported that they had *started* to dry laundry on radiators following the introduction of the new technology, however. User interviews suggest this may be due to existing understandings about heating efficiency and condensation, but access to alternative ways to dry laundry such as tumble driers or airers may also be important. Where hybrid heat pumps replaced boilers with hot water tanks, households sometimes lost space used to dry or air laundry, and some interviewees suggested this exacerbated their use of radiators for these purposes.

Unlike changing appreciations of daytime heating, users typically preferred to maintain cooler temperatures while they slept. Some users, such as those already using thermostatic radiator valves (TRVs) to avoid heating their bedroom, never experienced night-time heating. However, many interviewees experienced uncomfortably warm night-time temperatures and/or troublesome noises from the heating system at some point during the trial.

Such experiences often prompted practical learning in the form of changing use of controls, such as turning down TRVs on bedroom radiators, or turning down night-time heat settings in the app-based controls. While the intention of these responses is to avoid discomfort, they can also be influenced by users' understandings about how to heat efficiently or how to use controls, which they already held or which they developed during the trial. For example, Alan explained that he used TRVs to avoid the effects of night-time heating, because to change the 'sleep' temperature settings in the app would mean:

> "You're defeating what you're trying to do then, aren't you? You're warming up from nearly zero, up to where you want it. So it's back to the old system, then, before they put this in." *(Alan, follow-up user interview).*

Alan's response to discomfort allowed him to avoid warmer temperatures in his bedroom, but maintained the efficiency benefits of night-time heating in other rooms. This solution was informed by Alan's pre-existing access to and understanding of how to use TRVs, but also his newly constructed understanding that continuous heating is more efficient. This indicates that cognitive learning can also influence practical learning about the new technology.

Changes in the use of controls typically allowed users to avoid discomfort, but as Jim's example illustrates, this was not always the case:

> "We've actually woken up with it being so hot in the bedroom - the radiator's turned down on the frost setting in our bedroom - well, it seems a bit counter-productive opening the window when you've got the heating on, so we don't tend to open that. Whereas, perhaps, we would have had the window open if the heating hadn't been on, if it was too warm" *(Jim, follow-up user interview).*

If users are unable to resolve discomfort this can lead to practical learning that is less in line with the most efficient use of the technology. Mike's practical learning, described in Section 4.2, resulted in him effectively bypassing the operation of the smart controls, and was the culmination of several attempts to avoid night-time heating operation after himself and his wife were repeatedly kept awake. It could be possible to modify smart controls to offer users options to restrict night-time heating, but as this would reduce efficiency, it is interesting to consider alternative approaches to avoid discomfort for users.

Most interviewees either did not experience discomfort with the hybrid system or were able to easily resolve issues by changing how they used the heating controls installed in their homes, drawing on their pre-existing understandings about heating their homes and new understandings they constructed as part of the trial. However, Section 6.1 discusses opportunities to avoid discomfort for the remaining users, and to reduce intensification of drying laundry on radiators.

5.3 Constructing the meaning of smart hybrid heat pumps

Symbolic learning involves users constructing the *meaning* of the technology; meaning can influence future technology uptake when shared socially (Sørensen, 2013). Interview findings suggest that meaning is constructed during both uptake and use of SHHPs. Information provision can influence this learning at both stages, but is not the only factor at play.

At uptake, users' meanings about SHHPs appear to be largely informed by trial recruitment messages, since these are similar to commonly stated motivations to take part in the trial such as expecting to save money on heating bills and wanting to help the environment. In addition, many interviewees associated smart controls with ideas of increased comfort and convenience; for some users, these meanings seemed to also be influenced by pre-existing ideas about smart control, automation, or technological progress generally.

During use, additional symbolic learning can occur as users gain experience of SHHPs. "Just getting used to the system" meant Hayley moved from finding the idea of smart control "a bit scary" (initial user interview) to seeing the SHHP as "like an old system… it doesn't worry me at all [now]" (follow-up user interview). When experiences align with existing routines, this may contribute to the construction of more positive meanings. For example, some users who never experienced or easily resolved discomfort from night-time heating developed positive meanings about the warmer temperatures they experienced on rising during the night or early morning. Anne (follow-up user interview) took this as a sign "it's keeping the house really well warm" while Sophie (follow-up user interview) said the continuous warm temperatures were "probably my favourite thing about it". By contrast, users may develop negative meanings if they experienced discomfort that they are unable to easily resolve. Jim ultimately found night-time heating "a bit too unbearable" (follow-up user interview); similarly, before Mike learned how to avoid automated night-time heating, he explained that "literally there was no way to shut the thing off, so it did get a little bit annoying" (follow-up user interview).

The 'FREEDOM Project Final Report' (2018) suggests that providing information on cost and efficiency will lead users to accept unfamiliar patterns of heating. Laura's symbolic learning demonstrates this can be the case: she contacted the trial organiser after hearing noises from the heating system during the night, and started to see night-time heating more positively after being told it would reduce her heating costs:

> "It's not hot at night-time. It's hot, warmer than people would… yeah. It does go off, but it doesn't drop as much as people would think. But that's fine, because I know why" *(Laura, follow-up user interview)*

However, for Laura the cost of heating with LPG was a major ongoing concern; her husband, who Laura felt "just [doesn't] want to listen to the reasons why" (follow-up user interview) remained unhappy about night-time heating. Previous research has found that financial incentives are important to users at the point of uptake, with other concerns becoming more important once heat pumps are in use (Winther and Wilhite, 2015).

Interestingly, interviewees' symbolic learning also appeared to be mediated by the meanings they attached to participating in a trial. Even when they were seen as problems, many users perceived unexpected patterns of heating as something to be expected:

> C: "It is an experiment after all… Because we've had a few problems with it, haven't we?"
> A: "Yeah. Like I said, when it's warming up before it should, and coming on in the middle of

the night." *(Alan and Carol – follow-up user interview)*

Many interviewees interpreted issues they experienced as trial "teething problems" (Anne and Cai; Clive; Jim and Rachel; Lucy; Ruth and Harry follow-up user interviews); others apparently wanted to cooperate with what they perceived as the trial's objectives, or were grateful for receiving free heating equipment: as Clive commented, "You got it [SHHP] for free, don't moan!".

Overall, user interviews suggested symbolic learning can occur at the point of uptake and through differing experiences of the patterns of heating provided by SHHPs during use. During use, symbolic learning may only sometimes be influenced by information provision and cognitive learning. Given the importance of smart controls, the influence of the trial context on symbolic learning about heating patterns that might be linked to their operation (see Section 4.3) deserves further attention.

Section 6.1 discusses possible opportunities to influence users' symbolic learning about SHHP.

6. Policy implications of considering user learning

This section first discusses implications for heat decarbonisation policy, directly related to users' learning about SHHPs during the FREEDOM Project trial. Section 6.2 then discusses some broader implications of considering user learning in energy policy.

6.1 Policy implications of users' learning about smart hybrid heat pumps

Section 4 identified a number of learning *outcomes* with relevance for UK heat decarbonisation policy, given that user learning about new technologies can occur at a societal scale with lasting implications for technological development (Sørensen, 2006). For example, users' learning that heat pumps are inadequate as a sole heating technology challenges the expectation that rolling out hybrids would facilitate any later to switch to full heat pumps (if this is desirable) by increasing users' familiarity with heat pump technology. Meanwhile, certain ways in which users learn to use heat and use controls could reduce the technical benefits hybrid heat pumps are expected to deliver.

The remainder of this sub-section is based on the analysis of learning *processes* in Section 5. It discusses approaches that might influence users' learning to promote certain outcomes about the meaning and use of SHHPs. Following the structure of Section 5, it begins by discussing information provision and cognitive learning, before moving on to discuss practical and symbolic learning. Table 2 provides a summary overview of what interviewees learned about smart hybrid heat pumps, how this learning was constructed, and the policy implications of both.

Firstly, the analysis in Section 5.1 identifies that users select which information they pay attention to. This suggests that *better tailoring information to households' needs* could make information provision more effective by not overwhelming users with information they are likely to ignore, but also presenting relevant information in a way that speaks to their own needs and interests. Secondly, it suggests that *communicating information in a way that makes sense to users* might be enabled by paying attention to how they construct understandings from the information they receive. For example, talking about energy *cost* rather than efficiency might help users to understand that heat pumps use a higher proportion of electrical energy relative to ambient heat energy at lower outdoor temperatures – and thus cost more to run at these temperatures – but avoid the misconception that heat pumps are *ineffective* at lower outdoor temperatures, which some interviewees constructed from their understanding of the term 'efficiency'. Similarly, Judson *et al.*, (2015) suggest that it is easier for households to understand energy use expressed as cost rather than more technical measures such as kWh.

<table>
<tr><th>What did users learn about smart hybrid heat pumps?
(see Section 4)</th><th>How was learning constructed?
(see Section 5)</th><th>Policy implications of what and how users learned
(see Sections 4 and 6)</th></tr>
<tr><td>Heat pumps cannot provide adequate heating and hot water without a gas boiler (C).</td><td>Learning about heat pumps as part of a hybrid system where familiar gas boilers provided some services (C).

Ignoring written information and misunderstanding technical language used by installers (understanding ‘efficient’ to mean ‘effective’) (C).</td><td>What: challenges expectation that experience of hybrids increases acceptance of full heat pumps (C).

How: Verbal information about expense rather than efficiency may help to avoid this misconception (C).</td></tr>
<tr><td>Pre-existing routines of drying laundry on radiators reinforced or intensified (P).</td><td>Routine aligned with more constant heating provided by SHHP. Some users also lost drying space (if the SHHP replaced a boiler with hot water tank) (P).</td><td rowspan="2">What: decreased system efficiency and reduced energy savings. Expected benefits of fuel switching, mediated by smart controls, may not be realised (P). Negative meanings associated with unresolved discomfort may impact further technology uptake (S).

How: material changes (e.g. provision of TRVs, spaces to dry laundry where not available) and effective information on how and why to use them, may influence laundry drying; use of controls; and help to avoid discomfort (C, P, S).

Some users may benefit from follow-up contact to help address issues not predicted during installation (C, P, S).</td></tr>
<tr><td>Unintended use of control interface, circumventing operation of smart controls (P).</td><td>Followed repeatedly being kept awake by heating system operation, and failure of intended use of controls to resolve this (P).

Discomfort was usually resolved by changing use of controls such as TRVs but, if not, frustration and annoyance can result (P, S).</td></tr>
<tr><td>Low awareness of demand response tested during the trial (C).

Attributing unexpected patterns of heating to trial context (S).</td><td>Installers avoid over-burdening users with information (C).

‘Trial’ taken to mean technology unproven or in development – ‘teething problems’ should be expected (S).</td><td>What: awareness of smart controls should be given more attention to promote transparency and avoid mistrust (C, S).

How: effective information provision may increase understanding of demand response (C). Cognitive understandings about cost and efficiency are not sufficient for all users to accept discomfort (S).</td></tr>
</table>

Table 2: Summary of what and how users learned about smart hybrid heat pumps in the context of the FREEDOM Project trial, and implications for policy. *C*, *P,* and *S* indicate points related to cognitive, practical, and symbolic learning. Section 6.1 provides more detail on ways in which the three types of learning may be linked.

Interview findings indicate that *practical* learning can also be influenced by users' pre-existing or newly constructed understandings about efficient heating and how to use controls. This suggests that effective information provision about, for example, the efficiency losses of drying laundry on radiators might help to avoid the intensification of this routine. On the other hand, interview findings suggest the limitations of information provision and cognitive learning. Understanding how to use heating controls did not always allow users to avoid discomfort; similarly, it seems questionable whether knowledge of the efficiency penalty would prevent the use of radiators to dry laundry if no alternatives are available. Therefore, supporting *complementary material changes* in the home could go further to influence practical learning about SHHPs. These might include ensuring access to alternative ways to dry laundry and ensuring thermostatic radiator valves (TRVs) are installed in bedrooms to help more users avoid uncomfortable night-time heating. However, practical solutions may not always be so obvious: some interviewees were uncomfortably warm despite turning down bedroom TRVs, or were kept awake by noise rather than higher temperatures. Installers used technical surveys to plan SHHP installation. Extending these to consider how the distinct features of the new technology might play out in different houses and households could provide an early opportunity to identify possible issues and make tailored suggestions or even implement changes.

Material changes such as these could also influence symbolic learning (the construction of meaning). Interview findings reveal that whether users initially experience discomfort, and how easily they can use controls to avoid it, can make the difference between developing positive or negative meanings (effectiveness or frustration) for the same technology characteristic, namely night-time heating. Information provision and cognitive learning could support the use of new and existing controls. For some users, cognitive learning about cost or efficiency benefits can also play a direct role in construction of meaning – however, for other users experiences of discomfort may be more important. Effectively attending to symbolic learning might be even more important in a wider roll out of SHHP, because interview findings suggest that the meanings attached to participating in a trial made interviewees more tolerant of unexpected heating patterns.

Finally, because this analysis reveals that practical and symbolic learning continue with experience of the technology, it suggests that more effective policy would support ongoing guidance that can be *tailored based on households' unfolding experiences* over time. During interviews, installers reported that many users contacted them to seek help as the trial progressed, but user interviews revealed this was not always the case. A follow-up telephone call from installers could help to address issues or questions that arise after technology installation ('FREEDOM Project Final Report', 2018). This could also provide an opportunity for installers to support households' learning based on their unfolding experiences with SHHPs, through providing further, tailored information, and/or support with any material changes that could help to integrate hybrid heat pumps into daily routines.

This discussion suggests that installers are in many ways well placed to support users' learning. Installers communicate with users face-to-face, and it may be easier to tailor verbal, rather than written, information to households' needs (Isaksson, 2014). User and installer interviews suggest that, similarly to the findings of Owen, Mitchell and Gouldson (2014), installers already attempt to tailor the information they provide to users; that relationships with local installers may encourage users' trust in the advice they receive; and that at least some users already contact installers for help with emerging issues. Furthermore, installers already conduct pre-installation technical surveys. Gram-Hanssen *et al.*, (2016) and Hargreaves, Wilson and Hauxwell-Baldwin (2017) suggest that improved communication between installers and users could be achieved through expanding existing installer certification schemes. This could also include training on material changes that could support practical and symbolic learning, such as the installation of TRVs in bedrooms. However, asking installers to take on this role is likely to present challenges as well as opportunities. Installer interviews suggest that although installers attempt to tailor information provision, they find it hard to assess users' understanding, and rely on leaving behind written manuals that few users read. Furthermore, some installers may feel that explaining the operation of new heating technologies and helping users to control them is too difficult (Owen and Mitchell, 2015) or simply not their responsibility (Gram-Hanssen *et al.*, 2016). Any policy based on user learning should therefore consider whether installers, or other actors, such as users' peers (Judson *et al.*, 2015), have the necessary skills and opportunities to influence different types of learning.

6.2 Broader energy policy implications of considering user learning

Beyond the recommendations outlined above, this analysis helps draw attention to a number of broader policy implications associated with considering user learning. Firstly, the analysis presented in this paper suggests that when policy advice is based on technology trials, consideration should be given to how the trial context may have influenced findings about users (see also Winther and Bell, 2018). More generally, it adds to calls for energy policy to think beyond information provision and economic incentives as ways to engage with households and end users (Labanca and Bertoldi, 2018; Jensen *et al.*, 2019; Royston and Foulds, 2019), and highlights that it is relevant for policy to consider new technologies' *use*, as well as uptake (Sørensen, 2013; Judson *et al.*, 2015; Nyborg, 2015). Because households and users are heterogeneous, and user learning continues over time, considering learning implies identifying opportunities to flexibly respond to and influence learning as it emerges. This is quite different to the 'fit and forget' approach to new end-use technologies implied by a focus on technology uptake, and implies a less deterministic approach to policy making (Sørensen, 2013; Jensen *et al.*, 2019).

Because this paper took current policy expectations as a starting point for analysis, it focused on 'unwanted' (Isaksson, 2014) user learning that might pose a risk to fully achieving the expected benefits of SHHP. However, user learning can also represent an opportunity to create changes in routines or technologies that improve sustainable outcomes (see, for example, Hyysalo, Juntunen and Freeman, 2013; Vadovics and Goggins, 2019). Drawing attention to user learning also invites reflection on the role that learning itself can play in reducing domestic carbon emissions.

7. Conclusion and Policy Implications

New end-use technologies are expected to play an important role in reducing carbon emissions. In the UK, the Committee on Climate Change has recommended the large-scale roll out of smart hybrid heat pumps (SHHP), based on expectations that uptake of this innovative heating technology could contribute to pathways of decarbonisation for domestic heating. Hybrid heat pumps potentially offer several advantages compared to full heat pumps, such as requiring less additional generation and network capacity and providing greater electricity system flexibility. Alongside decarbonisation of the gas grid they offer a pathway to greatly reduce carbon emissions from home heating, but they are also seen as providing option value by facilitating any later transition to full heat pumps if this is desirable.

While energy policy often focuses on technology *uptake*, this paper focusses on the policy relevance of understanding SHHPs' *use*. It applies concepts from domestication theory – which explains users' engagement with new technologies in terms of learning – to analyse interviews and observations with 14 households and two installers participating in the trial of SHHPs which informed the advice of the Committee on Climate Change.

Analysing users' learning about how SHHPs work, how to use them and what symbolic meaning they carry identified a number of policy-relevant findings. Over time and on a societal scale, such learning could impact upon the heat decarbonisation pathways envisaged by the Committee on Climate Change; however, analysing learning processes can also suggest opportunities for policy to influence users' learning.

Learning about how hybrid heat pumps work:

- The Committee on Climate Change expect that experiencing a hybrid system would increase UK households' familiarity with and acceptance of full heat pumps, in a scenario where it is desirable to roll these out in the future. However, this expectation is challenged because users' learning about hybrid heat pumps may lead them to (wrongly) understand that heat pumps are unsuitable as a sole heating technology.
- Users could be supported to understand the functioning of the new technology by providing information that is tailored to their needs and communicated in a way that makes sense to them. For example, information that heat pumps operate less efficiently at lower outdoor temperatures can be understood to mean they do not provide effective heating; communicating in terms of 'higher cost' rather than 'lower efficiency' might be more easily understood, and avoid this misconception.

Learning about how to use smart hybrid heat pumps:

- Smart controls that mediate fuel switching between electricity and gas are essential to realise the expected technical benefits of SHHPs. However, if users experience discomfort it is possible for them to effectively bypass the operation of smart controls via unintended use of the user interface. In addition, energy savings could be reduced if users intensify the routine of drying laundry on radiators because it aligns with the more constant heating provided by SHHPs.
- More effective information provision can help users to develop more efficient ways to use SHHPs. Perhaps more importantly, material changes in the home such as installing thermostatic radiator valves or creating spaces to dry clothes, could help to integrate SHHPs into households' existing routines – reducing rebound effects and avoiding discomfort.

Learning about the meaning of smart hybrid heat pumps:

- The trial concluded that users accepted smart control, but this apparent acceptance may have been influenced by the trial context, meaning this conclusion deserves further attention.
- Helping users to avoid discomfort via effective information and appropriate material changes could also encourage users to develop more positive meanings about the technology. If users experience discomfort or other concerns, providing information on, for example, cost benefits is unlikely to be sufficient for all users to develop positive meanings about the smart hybrid heat pump system.

This analysis also indicates that learning proceeds over time, so that engaging with users after a period of use could allow any inputs to be better tailored to individual households' experiences. Installers may be well placed to provide this kind of support, but there are challenges as well as opportunities in asking them to take on this role, and other approaches to influence users' learning could be explored.

More broadly, this analysis adds to arguments that rather than focussing solely on technology uptake, information provision, and economic incentives, policy aiming to reduce carbon emissions from domestic energy use should consider technology *use*, and the ways in which users learn about technologies as they become part of their daily lives. It suggests achieving this may require flexibility: to respond to heterogeneity between different users, and to user learning that emerges over time. Altogether this implies a less deterministic approach to policy making. While this paper has discussed recognising and avoiding user learning that could represent a risk to achieving policy objectives, users' learning can also represent an opportunity to reduce emissions from home energy use, for example by changing routines. Better understanding how and why users learn about new technologies could contribute to reduce emissions from home energy use in both ways.

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